Grand Challenge Area

Manufacturing at the Nanoscale: New Methods for Traditional and Emerging Technologies

Challenge

Because nanostructures have little mass and are dominated by surface-area effects and size effects, the processes and equipment for nanotechnology-based manufacturing are expected to differ significantly from those currently used. Nanofabrication thus requires the invention of new instruments, measurement tools, models, methods, and standards to characterize nanoscale materials and processes. Only through such developments can the manufacture of commercial volumes of products—with a high degree of repeatability—become economically viable. Manufacturing at the nanoscale is a central challenge for the NNI because it is a prerequisite for realizing the benefits of nanotechnology. A concomitant challenge is the creation of high quality, diverse nanoscale building blocks that enable their assembly into large systems.

Vision

Manufacturing at any scale is a complex endeavor involving the use of many types of equipment and processes to transform raw materials into tangible products with desired properties or performance characteristics, generally in large quantities. Atoms and molecules are the raw materials for nanotechnology-based manufacturing. And only those raw materials that will become part of the final product will be selected for the nanofabrication process.

This bottom-up approach differs greatly from that of current manufacturing processes that involve assembling large quantities of materials, from which product parts are cast, machined or otherwise derived and waste products are left for disposal.

Nanostructured materials, devices, and systems will be manufactured with precise control over the location of individual atoms and molecules. The resulting nanoscale components will be hierarchically integrated and incorporated into macroscale devices and systems. Innovative ideas will be required to allow for nanoscale positioning; addition and removal of material; directed self-assembly; and biomimetic (i.e., life-imitating) fabrication paradigms.

Since an entirely new approach to manufacturing is required, there is a need to concurrently develop new tools and facilities to support this effort.

Agency Participation

(leads in bold)

DOE	Novel synthesis and processing approaches
EPA	"Green manufacturing" with minimal waste streams
IA	Prototype functional nanodevices
NIST	Measurement technology and standards for process characterization and quality control
NSF	Research for manufacturing processes, new theoretical models, and simulations
USDA	Biological manufacturing

In addition to the above agencies, which have specific efforts in manufacturing at the nanoscale, each NNI agency is committed to this grand challenge area and will incorporate it into their plans as appropriate to their respective mission-specific programs.

Research Example: Dip-pen Nanolithography—A new approach to nanoscale fabrication (supported by NSF and DOD)

The ability to make nanoscale patterns on surfaces is a critical process in, for example, the manufacture of electronic circuits, the performance of high-throughput biomedical research, and the design of advanced sensors. However, the cost of extending currently used methods to smaller and smaller scales is substantial. Researchers at Northwestern University have developed a new approach called "Dip-Pen Nanolithography" (DPN) that utilizes an atomic force microscope tip as an "ink pen" (Figure 8). DPN is a direct, single-step process that does not require the use of patterned masks or light-sensitive films, or other steps to form patterns on a substrate. Additionally, it may be performed under ambient conditions. DPN provides a reliable approach to writing nanoscale lines of a variety of molecules onto various solid surfaces. Repetitive patterns of nanoscale lines may be created in parallel using an array of writing tips. The inventors of the DPN technology have formed a start-up company that plans to develop products and services for the fabrication of patterned nanostructures.

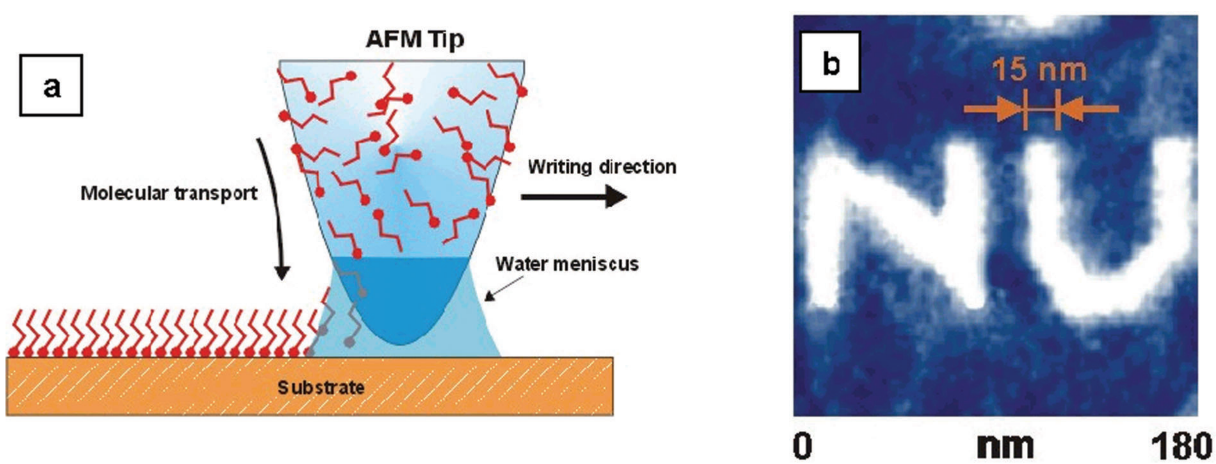

Figure 8. (a) Cartoon showing how dip-pen nanolithography "writes" molecules onto a substrate. A major advantage of this process is that it creates a nanostructure pattern on a surface in one step. Conventional processes to create such a patterned nanostructure require up to five complex steps and very sophisticated fabrication tools. (b) Linear force microscope image of an acid "ink" patterned on a gold substrate. The patterned feature size is 15 nm and spatial resolution is ~5 nm (courtesy C. Mirkin, Northwestern University).